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Volume flow rate

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Summary Vascular imaging of carotid and vertebral arteries may not be sufficient to evaluate the patients with stroke and other cerebrovascular disorders. Cerebral blood flow measurement can add information to increase the accuracy in diagnosis, assessment, and plan of management in these patients. There are many noninvasive quantitative methods to measure cerebral blood flow including volume flow rate measured by ultrasound. This article addresses mainly the different ultrasound techniques to measure cerebral blood flow. Clinical applications, volume flow rate in normal and abnormal conditions with a case example, and advantage and disadvantage of the ultrasound techniques are also described.

Introduction

Vascular imaging of carotid and vertebral arteries may not be sufficient to evaluate the patients with stroke and other cerebrovascular disorders. Cerebral blood flow (CBF) measurement can add information to increase the accuracy in diagnosis, assessment, and plan of management in these patients.

Methods for measurement of cerebral blood flow

There are many noninvasive quantitative methods to measure CBF including stable xenon-enhanced computed tomography, single-photon emission computed tomography, positron-emission tomography, and magnetic resonance imaging. These methods are reliable and accurate for CBF measurement. However, they are rather expensive and requiring to transfer patients to the imaging or radio-nuclei facility which may be a limitation in the critical ill, sedated, or ventilated patients [1].

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Volume flow rate measurement by ultrasound

Several ultrasound methods have been used to measure volume flow rate (VFR) of CBF such as Doppler method [2], color velocity imaging quantification (CVIQ) [3], quantitative flow measurement system (QFM) [4,5], and angle-independent Doppler technique by QuantixND system [6]. The common carotid artery (CCA) is quite accessible and reliable to measure VFR, whereas it is more difficult to obtain reliable VFR in the internal carotid artery (ICA) or vertebral artery (VA) due to the deeper vessels. VFR measurements are usually obtained at 1.5—2.0 cm below carotid bifurcation in CCA, 1—2 cm above carotid bifurcation in ICA, and between the 4th and 5th cervical vertebra in the inter-osseous segment of VA using high-resolution linear probe with pulsed Doppler imaging [7].

Doppler method

Doppler method can estimate VFR at a specific point in a vessel by multiplying the flow velocity with cross-sectional lumen diameter at that specific point in time (Fig. 1). However, Doppler method does not provide a profile of instantaneous peak velocities across the entire vessel and

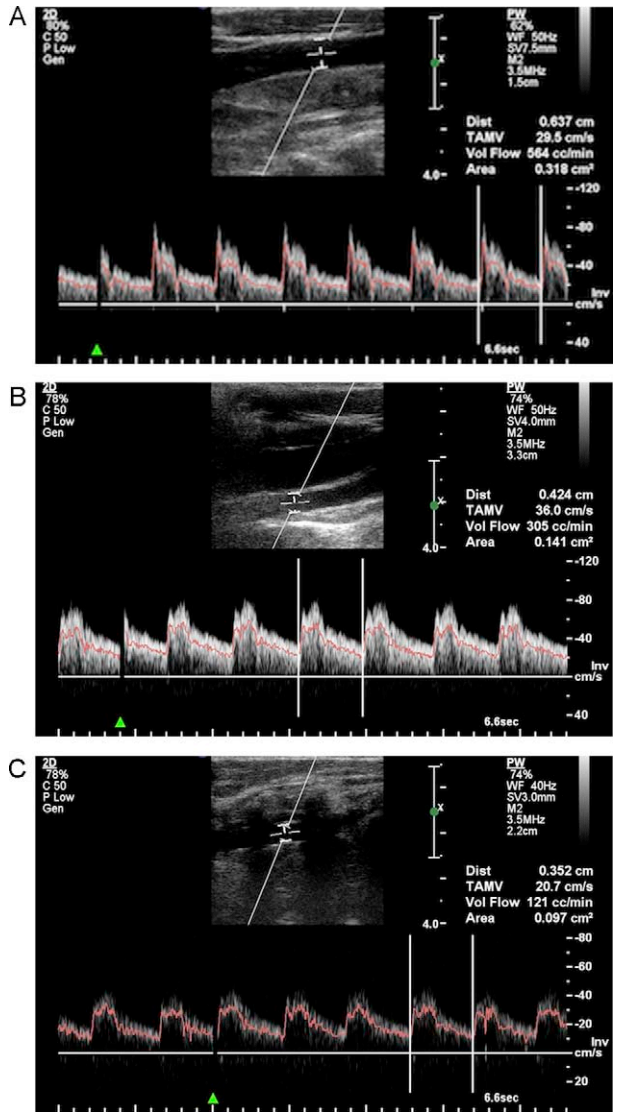

Figure 1 VFR measurements using Doppler method in CCA (A), ICA (B), and VA (C) with large sample volumes across the entire vessel lumens.

cannot adjust for changes in the flow lumen throughout the cardiac cycle.

Color velocity imaging quantification

CVIQ measures VFR by using time-domain processing with color velocity imaging combined with a synchronous M-mode color display to provide an instantaneous profile of the peak velocities across the flow lumen as well as a continuous estimate of the diameter of the flow lumen throughout the cardiac cycle (Fig. 2). By assuming a circular vessel and axial symmetrical flow, CVIQ can be calculated automatically with built-in software.

Quantitative flow measurement system

QFM is comprised of two components. One component uses one transducer with ultrasonic echo tracking to measure vessel diameter, and the other uses three transducers with continuous Doppler independent of incident angles to measure absolute blood flow velocity. QFM can be calculated using a vessel diameter in cross-sectional area and the absolute blood flow velocity.

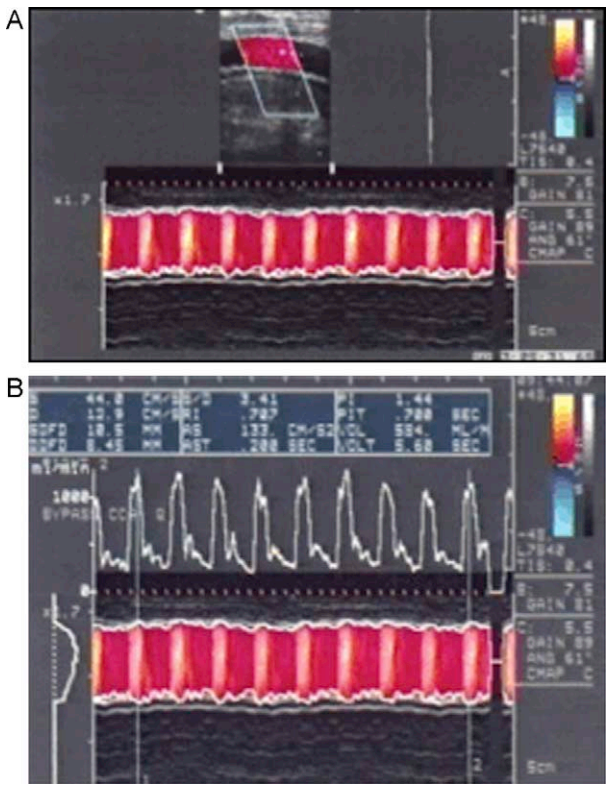

Figure 2 VFR measurement using CVIQ in CCA with the optimal color box across the entire lumen in M-mode display (A) and synchronous instantaneous peak velocities across the flow lumen (B).
With permission from Professor Charles H. Tegeler.

Angle-independent Doppler technique by QuantixND system

QuantixND system is an angle-independent Doppler technique which employs dual ultrasound beams within one insonating probe in a defined angle to each other. The real time information is stored automatically and analyzed by the computer.

VFR measured by CVIQ and Doppler method

The mean values of VFR in 50 healthy subjects as measured by CVIQ and Doppler method are 340.9 ± 75.6 and 672.8 ± 152.9 ml/min for CCA, 226.9 ± 65.0 and 316.2 ± 89.1 for ICA, and 92.2 ± 36.7 and 183.5 ± 90.8 for ECA, respectively [2]. VFR is higher in male compared to those in female and decreasing with increasing age. Doppler method tends to overestimate VFR and CVIQ seems to be more accurate than Doppler method to measure the carotid artery VFR. However, CCA VFR measured by CVIQ and Doppler method has no difference in 0-95% ICA stenosis but CCA VFR by

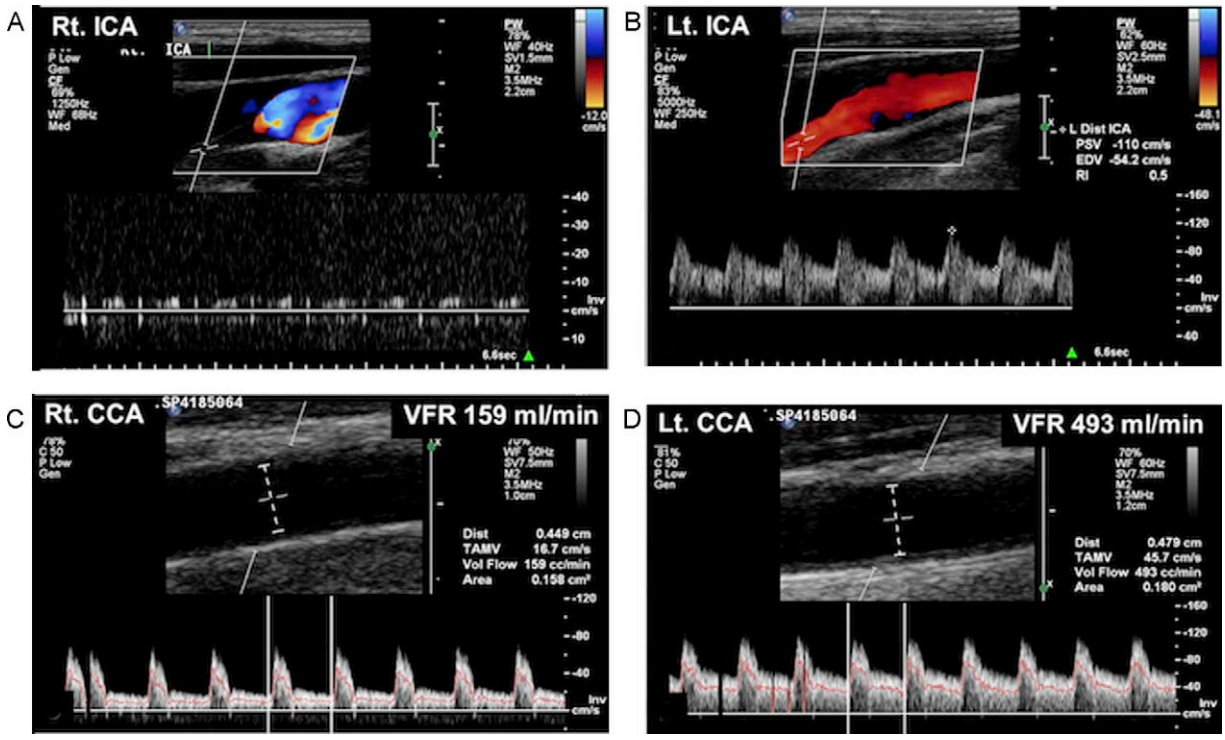

Figure 3 CCA VFR measured by Doppler method in a 46-year-old male with right ICA occlusion. Color flow imaging shows right ICA occlusion (A) and normal left ICA (B) with right CCA VFR of 159 ml/min (C), and left CCA VFR of 493 ml/min (D).

Doppler method is higher than that measured by CVIQ in 95—100% ICA stenosis [8].

Clinical applications

VFR measurement can be useful for grading carotid stenosis especially with coexisting contra-lateral carotid stenosis or occlusion to avoid overestimation of degree stenosis by using only flow velocity criteria, evaluating collateral flow and cerebrovascular reserve, identification of feeders and use as follow-up study in intra-cranial arteriovenous malformation, quantification of hemodynamic changes in subclavian steal syndrome, assessment of vasospasm in subarachnoid hemorrhage, and monitoring of CBF before and after carotid endarterectomy [9,10]. In addition, there is a direct correlation between middle cerebral artery mean flow velocity (MCA Vm), CCA VFR, and end-expiratory CO_2 in normal subjects. The MCA Vm and CCA VFR increase 6.1% and 5.3% per mmHg increase in end-expiratory CO_2, respectively, and the MCA Vm increases 0.3 cm/s for each 1 ml/min increase in CCA VFR [11]. Therefore, measurement of CCA VFR changes during CO_2 inhalation may be an alternative method to measure cerebral vasoreactivity in the patients with inadequate temporal windows.

VFR in carotid stenosis

CCA VFR measured by Doppler method and CVI-Q at different degree of carotid stenosis are 359 ± 130 and 337 ± 96 ml/min, respectively, for the individuals without ICA stenosis, 310 ± 99 and 293 ± 133 ml/min for 50—75% ICA stenosis, 347 ± 80 and 195 ± 131 ml/min for 75—95% ICA stenosis, 152 ± 36 and 63 ± 25 ml/min for 95—99% ICA stenosis, and 125 ± 47 and 58 ± 22 ml/min for ICA occlusion [8]. The reduction of ipsilateral CCA VFR is present in the patients with severe ICA stenosis of 75—99% or ICA occlusion as shown in Fig. 3.

Conclusions

When comparing with other brain perfusion imaging techniques, VFR obtained with ultrasound does not provide values for each brain region, but represents only one value for each supplying vessel [10]. It may be limited by operator dependent, extra examination time, requirement for patient cooperation, extensive plaque formation, turbulent flow, and tortuous and asymmetrical vessels. Nevertheless, VFR measured by ultrasound is still the easiest, feasible, noninvasive, and repeatable bedside examination with no exposure to contrast media or radiation.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.permed.2012.03.008.

References

[1] Markus HS. Cerebral perfusion and stroke. J Neurol Neurosurg Psychiatry 2004;75:353—61.

[2] Ho SSY, Metreweli C. Preferred technique for blood volume measurement in cerebrovascular disease. Stroke 2000;31:1342—5.
[3] Eicke BM, Tegeler CH, Howard G, Myers LG. In vitro reliablity of flow volume measurements with color velocity imaging. J Ultrasound Med 1993;12:543.
[4] Furuhata H, Sugano R, Kodaira K, Aoyagi T, Matsumoto H, Hayashi J, et al. An ultrasonic Doppler method designed for the measurement of absolute blood velocity values. Med Elec Bioeng 1978;16:264—8.
[5] Mizukami M, Yamaguchi K, Yunoki K. Evaluation of occlusive cerebrovascular disease using ultrasonic quantitative flow measurement. Stroke 1981;12:793—8.
[6] Schebesch KM, Simka S, Woertgen C, Brawanski A, Rothoerl RD. Normal values of volume flow in the internal carotid artery measured by a new angle-independent Doppler technique for evaluating cerebral perfusion. Acta Neurochir (Wien) 2004;146:983—6.
[7] Peter Scheel MD, Christian Ruge, Uwe R, Petruch MD, Martin Schöning MD. Color Duplex measurement of cerebral blood flow volume in healthy adults. Stroke 2000;31:147—50.
[8] Likittanasombut P, Reynolds P, Meads D, Tegeler C. Volume flow rate of common carotid artery measured by Doppler method and color velocity imaging quantification (CVI-Q). J Neuroimaging 2006;16:34—8.
[9] Tegeler CH, Ratanakorn D, Neurosonology. In: Fisher M, Bogousslavsky J, editors. Textbook of neurology. Newton, MA: Butterworth Heinemann; 1998. p. 101—18.
[10] Wintermark M, Sesay M, Barbier E, Borbély K, Dillon WP, Eastwood JD, et al. Comparative overview of brain perfusion imaging techniques. Stroke 2005;36:e83—99.
[11] Ratanakorn D, Greenberg J, Meads DB, Tegeler CH. Middle cerebral artery flow velocity correlates with common carotid artery volume flow rate after CO_2 inhalation. J Neuroimaging 2001;11:401—5.